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Leeds & Northrup Apparatus

at the

Louisiana Purchase Exposition

1904

The Leeds & Northrup Co.

Makers and Dealers

ELECTRICAL MEASURING INSTRUMENTS

259 North Broad Street

PHILADELPHIA

30-804

THE apparatus described in this pamphlet will be found in and is a part of the exhibit of The National Bureau of Standards, in the Electricity Building.

The National Bureau of Standards is making an extensive working exhibit, which to a considerable extent duplicates their equipment at Washington, and it will maintain a large working staff at St. Louis.

By arrangement with the authorities of the Exposition, it is to act in an official capacity in calibrating and standardizing instruments for the Jury of Awards and in making tests for them.

In order to have the necessary apparatus to make this working exhibit without either depleting its equipment at Washington or extensively purchasing apparatus to duplicate it, the Director of The National Bureau asked us (among other manufacturers) to loan them apparatus to supplement that which they took from Washington. We gladly availed ourselves of this opportunity to have our apparatus at the Louisiana Purchase Exposition.

The exhibit of The National Bureau of Standards is in the Electricity Building, Space 29, and you are cordially invited to inspect our apparatus there.

Made by George H Buchanan and
Company at the Sign of the Ivy
Leaf in Sansom Street Philadelphia

Resistance Boxes and Wheatstone Bridges

For a very complete description of our Resistance Boxes and a general discussion of the best arrangement and general design of Resistance Boxes, Wheatstone Bridges, etc., see our pamphlet No. 1, which devotes 36 pages to the subject.

4400

4400. Decade Set and Wheatstone Bridge............$275 00

In this set we have combined the many improvements which we have recently made in this class of apparatus and we are confident that no high grade set on the market to-day offers so many advantages at so low a figure.

The Rheostat consists of five decades, one each containing coils of 1000, 100, 10, 1 and .1 ohm. An extra .1 ohm coil gives a total range of 10.000 ohms which can be varied by steps of .1 ohm. Our improved decade arrangement is used which has all the advantages of the old arrangements but uses only four coils to the decade and has the additional advantage of reducing the errors due to plug contacts. This arrangement will be made clear by the following explanation and diagrams.

1, 3, 3^1 and 2 ohm coils are connected in series as shown in Fig. 1.

Let the terminal of the 1 ohm coil and the 2 ohm coil and the points of union of the coils be numbered (1), (2), (3), (4), (5) as shown in Fig. 1. The current enters at point (1) and leaves the coils at the point (5) traversing 1, 3, 3^1, 2=9 ohms in all. If this series is multiplied by any factor n then n $(1+3+3^1+2)=$n 9 ohms. It will be seen that if the points (1) and (5) are connected all the coils are short circuited and that the

current will traverse zero resistance. If the points (2) and (5) are connected the 3, 3' and 2 ohm coils will be short circuited and the cur-

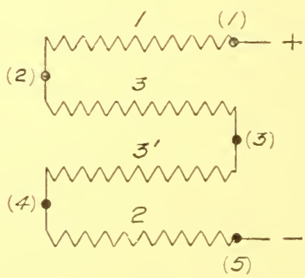


Fig. 1

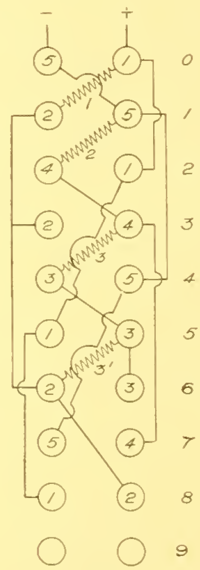
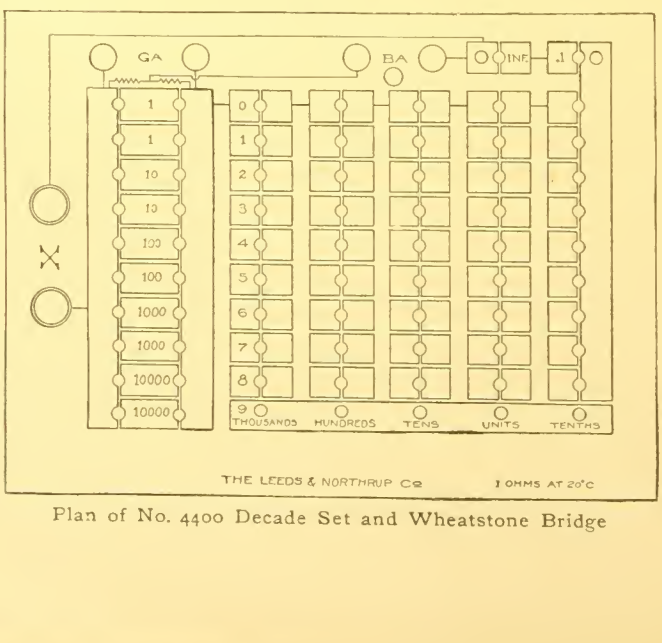


Fig. 2

rent will traverse 1 ohm. By extending this process so that we connect two and only two points at a time, it is possible to obtain the regular succession of values n (0, 1, 2, 3, 4, 5, 6, 7, 8, 9) the last value being



Plan of No. 4400 Decade Set and Wheatstone Bridge

obtained when no points are connected. The following table shows the points which must be connected to obtain each of the above values and the coils which will be in circuit for giving each value:

Value.	Points Connected.	Coils Used.
0=	(5—1)	0
1=	(2—5)	1
2=	(4—1)	2
3=	(2—4)	1, 2
4=	(3—5)	1, 3
5=	(1—3)	3^1, 2
6=	(2—3)	1, 3^1, 2
7=	(5—4)	1, 3, 3^1
8=	(1—2)	3, 3^1, 2
9=	(0)	1, 3, 3^1, 2

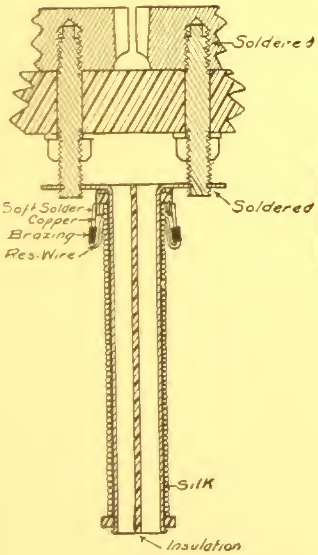


Fig. 4

Fig. 5

Fig. 2 shows our method of connecting these points two at a time with the use of a single plug.

The circles in the diagram represent two rows of ten brass blocks each. To the first two blocks at the top of the rows, the points 5 and 1 of diagram 3 are connected, to the second two the points 2 and 5 are con-

nected and so on, no points being connected at the last pair of blocks. It is evident that if a plug be inserted between the blocks 1 and 5, the points 1 and 5 of diagram 3 are connected giving the value 0, if between the blocks 2 and 5, the points 2 and 5 are connected giving the value 1 and so on. The value 9 is obtained when the plug is disposed of by being inserted in the last pair of blocks which have no connections.

Metal Spools

All of the resistances are wound on our improved metal spools which have a much greater ability to get rid of their heat than wooden spools and consequently will stand larger currents.

Fig. 4 gives a sectional view of this spool, and Fig. 5 a photographic view of the same spool mounted with a single pair of brass blocks.

The essential feature of the construction lies, in making to serve as terminals the two insulated metal halves of the spool upon which the resistance wire is wound. The insulation between the two metal halves is very high, and these halves are held firmly together by a ring of insulating material at the top and bottom. The metal spool so formed is covered with a layer of shellacked silk, and over this the wire is wound in uniform layers.

Improved Arrangement of Ratio Coils

This arrangement offers the following advantages. The coils are completely interchangeable. When a coil is connected in there is but one plug contact in series with it. It offers a simple method of determining the percentage accuracy of a measurement. There are ten ratio coils, two each 1, 10, 100, 1000, 10,000 ohms. All the ratio coils have one of their terminals connected to a common centre which corresponds to the bar marked C of Fig. 6. The other terminal of each coil is connected to a separate block. The bar A on one side of these blocks is joined to the rheostat and the bar B on the other side to an X post.

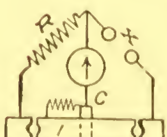


Fig. 6

In the ordinary use of this set of ratio coils two plugs only are used. One plug is inserted between the bar A and one of the blocks, 1, 1', 10, 10', etc., of the central row of blocks, and the other plug is inserted between the bar B and any one of the other blocks of the central row. There are two ratio coils of each value. In our high grade sets we use the values indicated in Fig. 6. They are, 1, 1'; 10, 10'; 100, 100'; 1000, 1000' and 10000, 10000'.

To obtain an even ratio, as 1000 to 1000', one plug would be inserted between the block 1000 and the bar A and the other plug between the block 1000' and the bar B. This disposition of the plugs connects the end of the 1000 ohm coil to the end of the rheostat and the end of the 1000' ohm coil to the X post. If now one plug is inserted between the 1000' block and bar A and

the other plug between the 1000 block and bar B the ratio arms are reversed; that is the 1000' ohm coil is connected to the end of the rheostat and the 1000 ohm coil to the X post. When uneven ratios are used the same ratio can be obtained by four different combinations. If we wish to obtain the ratio of one to ten, we can plug between A and 1, and B and 10, and get 1 to 10, or between A and 1', and B and 10, and get 1' to 10, or between A and 1, and B and 10', and get 1 to 10', or between A and 1' and B and 10', and get 1' to 10'.

To obtain the reciprocal set of ratios like the above we would plug:
A and 10, B and 1, and get 10 to 1,
A and 10', B and 1, and get 10' to 1,
A and 10, B and 1', and get 10 to 1',
A and 10', B and 1', and get 10' to 1'.

By using more than two plugs and connecting certain of the coils in parallel combinations a large number of other ratios may be obtained. For example, we can plug between A and 100 and 100' and between B and 1000, and get the ratio 50 to 1000. Or we can plug between A and 1000 and 1000' and between B and 100, and get the ratio 500 to 100.

This bridge arrangement offers a convenient method of measuring the sensibility of a bridge and galvanometer combination that is frequently applicable. If for instance the one ohm coil is used on either side, after a balance has been obtained the one ohm may be shunted with the 1000 ohm on the same side. This will make a variation of $\frac{1}{10}$ of 1% and the galvanometer deflection can be noted for this variation. In the same way the 1 ohm may be shunted with the 100 for a variation of 1% or with the 10,000 for a variation of $\frac{1}{100}$ of 1%. The ten ohm coil may be shunted with the 1000 for a variation of 1%, and with the 10,000 for a variation of $\frac{1}{10}$ of 1%.

In the above arrangement of ratio coils it is seen that errors due to plug contacts become practically nil because only two plug contacts enter the circuit and with even ratio, it is only the *difference* in the resistance of the two plug contacts that can effect the result. In measuring any of the ratio coils while in the box, it is only necessary to connect to the bar C, and to either the bar A or B and plug in the coils to be measured. In our boxes the bar C C is made of heavy copper and one of the galvanometer posts is connected to this bar by a heavy copper strap so that in measuring the ratio coils the resistance of the connections on the inside of the box may be neglected.

The terminals of the wire are brazed to copper terminals and these are soldered to the projecting brass lips at the end of the spool which attaches to the brass blocks. The brass studs which project through the rubber plate are soldered in the blocks, and the metal spool is secured in grooves turned in the ends of these brass studs and then soldered. Thus there is a continuous soldered connection from one block to the next between which is the resistance.

The above form of construction is mechanically strong. The maximum radiating surface is secured to the wire, while much of the generated heat is conducted away by the metal spool through the brass studs into the brass blocks on top of the box and thus dissipated.

Improved Plugs

The plugs are of generous size, have no sharp corners to hurt the hand and the heads are put on so that they positively cannot come off.

In Fig. 7 is shown a plan and section of one of these L type plugs.

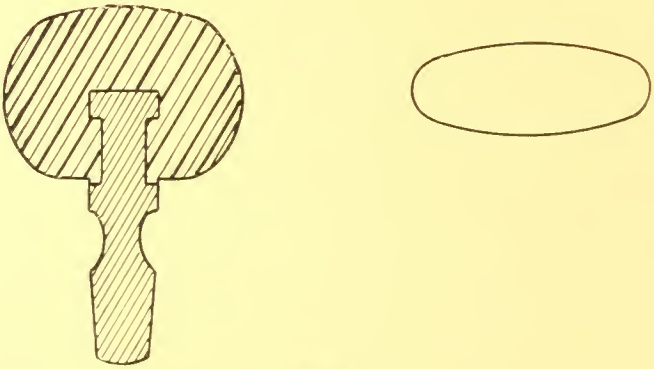
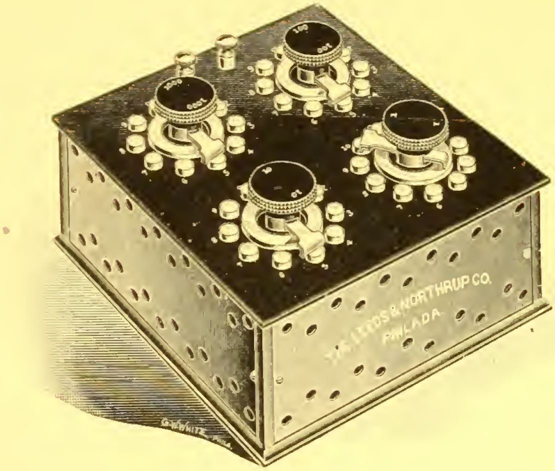


Fig. 7

The chief points to notice are the following. The taper is such that the plug will neither stick in so tight that it cannot be easily withdrawn, nor yet so that it will loosen itself. The taper part of the plug goes a little below the surface of the blocks, so rings will not wear into the plug which will form a shoulder and prevent the plug from being pushed in tight. The brass part of the plug which is moulded in the hard rubber top expands in the rubber head so the head cannot possibly work loose or turn. The rubber head itself is smooth and a flattened ellipsoid in shape and is moulded upon the brass post. This form of head is easily grasped and does not hurt the fingers with long use as do the diamond-shaped plug heads with sharp edges.

Decade Rheostat, Four Dials

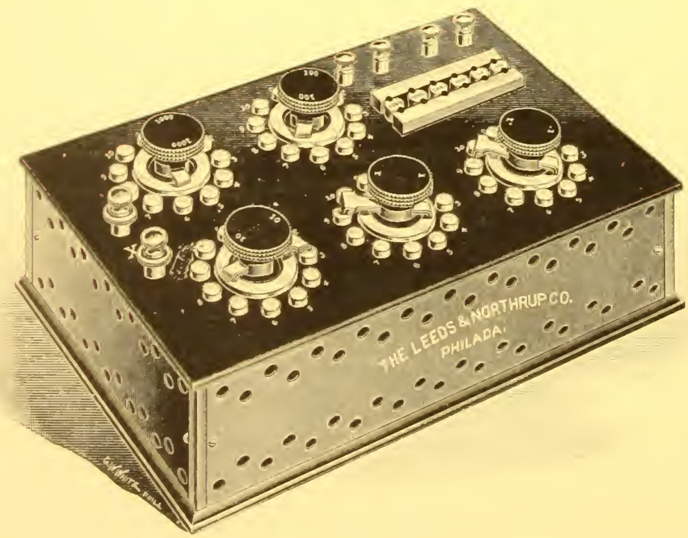
The dial switches of these rheostats are of a new and special construction which insures good contact. The range is 9999 ohms by steps of 1 ohm. The sides of the box are made of perforated metal so as to allow good air circulation and cooling. To increase the carrying capacity of the resistances the entire box may be immersed in oil. Both the box and the coils are made so that this will not injure them.



Wheatstone Bridge and Rheostat

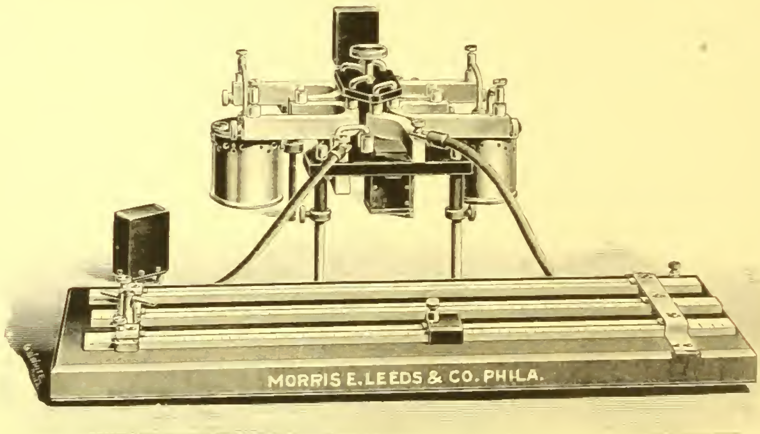
This is the same general construction as the last. There are five dials in the rheostat which has a total resistance of 10,000 ohms and may be varied by steps of .1 ohm. The bridge has two coils each of 1000, 100 and 10 ohms.

Special rheostats and wheatstone bridges using this dial construction can be made up with any number of dials.



Carey Foster Bridge

For a very complete description of our Carey Foster Bridge, directions for using it and general discussion of the Carey Foster method see our circular No. 9, The Carey Foster Bridge.



4204

4204. Carey Foster Bridge........................$150 00

Complete with set of 3 bridge wires, 2 shunts for them and 4 sets of ratio coils.

4214. Heavy Bar...................................$5 00

Of resistance metal of low temperature co-efficient; resistance determined and marked on it. To be used in the measurement of very low resistances.

The bridge as mechanically designed consists of two separate units.

One unit, which we will designate "the coil holder," consists of a hard rubber base upon which are mounted massive copper bars for holding and connecting the ratio coils and the resistance standards, also the commutating device for interchanging the standard and the coil under comparison.

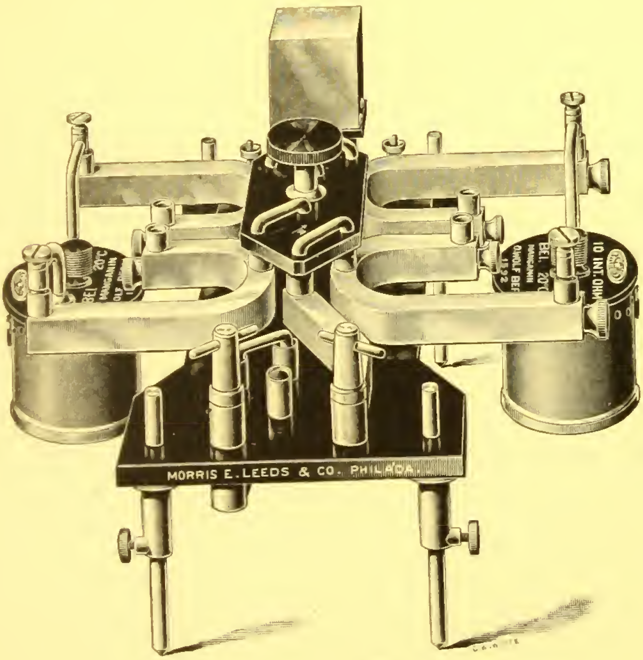
The other unit, which may be called the "bridge," consists of a hard wood base upon which are fastened the three slide wires and three boxwood scales. A sliding contact maker designed to give a contact having a uniform pressure on the slide wire, is also a part of the "bridge."

The two units are joined together electrically by large flexible copper cables. The two illustrations show the complete apparatus and the coil holder alone.

The copper bars which hold the standard and the coil under comparison are each provided with two sets of mercury cups. The outside set have a separation which adapts them to holding the terminal copper rods

of the standard coils of the Reichsanstalt Form, while the inside pair of cups are made to hold B. A. standards. Thus standards of the one form may be compared with those of the other form. An arrangement of this kind has been found to be of importance, since both forms of resistance standards are to be found in most laboratories.

The four ends of each pair of copper bars are also provided with massive binding posts which may be used to clamp resistances which are used as shunts. The remaining shorter copper bars which form the connections and leads are also very massive copper and are provided with deep mercury cups. All the copper work is protected from amalgamation with the mercury by being given a surface of unbuffed nickel plate.



Details of Coil Holder

The commutator switch, which occupies a central position over the base, is of very simple construction, of symmetrical form and **effects the interchange of the coils by a single half revolution.**

Three mercury cups near the front are provided for putting in circuit either one of the low resistance shunts. These shunts are made of the same resistance metal as the slide wires and are of practically zero temperature co-efficient, and can be relied upon to remain constant. A shunt is thrown in circuit by simply connecting two of the mercury cups with a heavy copper U-piece.

The shunts, themselves, are beneath the base and protected by being enclosed in a small box.

The ratio coils furnished with each bridge have resistances of 1, 10, 100 and 1000 ohms. They are contained in metal boxes and are provided with heavy copper terminals which fit into the four mercury cups at the back end of the base plate.

The base itself consists of a single piece of hard rubber ⅝" thick. It is provided with brass legs at each of its four corners which slide up and down in holes and enable the "coil holder" to be set at different heights above the table.

The slide wire bridge is provided with three different resistance wires. These wires are of special resistance metal and have practically a zero temperature co-efficient. The resistance of No. 1 wire per mm. is about .0004 ohms, of No. 2 wire about .0011 ohms and of No. 3 wire about .0057 ohms.

No. 1 wire when shunted with the shunt of lowest resistance is equivalent to a resistance of .00001 ohms per mm.

Each wire is stretched over a boxwood scale. Any one of the three wires is put in circuit, ready for use, by connecting it at one end by means of a massive clamp screw to a copper strap underneath the base.

This copper strap and another one to which the other ends of the three wires are attached are connected by heavy flexible copper cables to the coil holder. No error will be introduced by using shunts to the bridge wire, provided the resistance of these leads is negligible or does not change after a bridge wire has been calibrated.

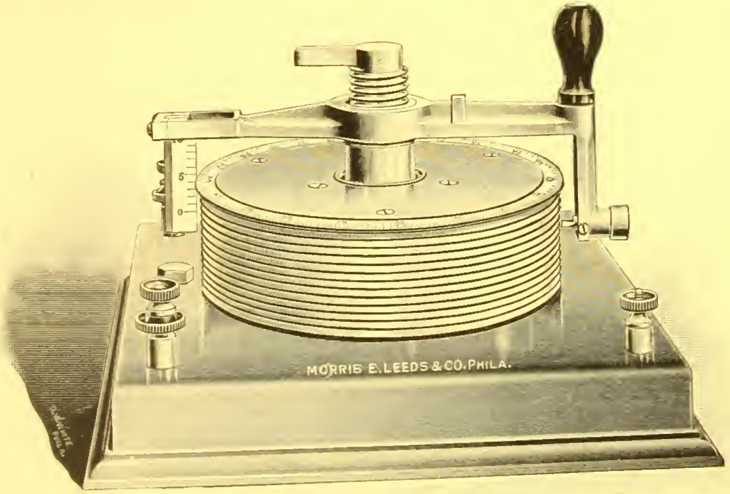
The slider used for making contact with the bridge wire has been designed with special care. It is mainly of hard rubber, so that the hand will not come accidentally in contact with any of the circuits. The button is provided with a double spring arrangement, so that when depressed with any force the same pressure of the contact piece is always brought to bear against the bridge wire. This prevents indentations and injury to bridge wire.

4256. Kohlrausch Slide Wire Bridge....................$80 00

This bridge was designed to have all the advantages of the original form of Kohlrausch bridge without its disadvantages. These are uncertain contact resistances in the bridge circuit due to the brushes through which the current passes to the wire and uncertain contact in the galvanometer circuit made by poor contact of the roller on the wire or of the roller on the rod on which it moved. To accomplish this we have made the contact movable and the polished cylindrical marble on which the wire is fastened fixed. In this way both ends of the wire have reliable soldered connections out to the binding posts, and the connections in the contact circuit are also soldered, except that found between the long nut moving on a large screw which moves the contact arm up and down as it rotates. This, on account of its ample size, is entirely reliable. The marble cylinder is 6" in diameter; the wire makes ten turns around it, and the total resistance is about 5 ohms. A vertical scale shows the number of turns, and the fraction of a turn is read from a circular scale, which is divided to 200 parts and can easily be estimated to tenths of a division.

The contact rubs on the wire continually and has been very carefully designed to make sure that it will always make a good contact and

that **it will not wear the wire.** It has been thoroughly tested in both of these particulars; in regard to wearing the wire as follows: We connected one of these bridges to a small motor so that the contact would rub backwards and forwards over a length of about 3″ of the wire near one end, and allowed it to run 6 hours. During that time it rubbed over the 3″ of wire more than 100,000 times. The middle point in resistance on the wire was measured before and after the test, and absolutely no difference could be noted due to the rubbing. The two measurements agreed with each other within 1-500 of 1%. It is accordingly evident that no error from this cause is to be feared. **The advantage of the rubbing contact over the rolling contact of the original form is very marked, and it is entirely reliable.**



4256

4257. Kohlrausch Slide Wire Bridge................. $100 00

With rheostat coils in the base.

This is the same as the above, but is mounted on a box in which there are rheostat coils of 1, 10, 100, 1000 and 10,000 ohms resistance. These are arranged so that they can be connected to either one or the other end of the bridge wire. They are wound so as to be noninductive and will introduce no noticeable errors even with the rapidly alternating current of an induction coil.

4244. Megohm Resistance Box....................... $200 00

The resistance is divided into five parts of 100,000 ohms each. Six pillars **petticoat insulated** are used, there being 200,000 ohms between each pair of pillars. There is a double binding post on each pillar so that they can be connected together with copper links. **The total resistance is wound on 40 spools** so that there are 25,000 ohms to the spool. Each spool is thoroughly insulated.

Resistance Standards

For more detailed information in regard to our Resistance Standards, see our Pamphlet No. 4 on Standard Resistances. This is a 16-page booklet in which the best design for standards and methods of using them are discussed.

4215

4215. Standard Resistance (Reichsanstalt Form) 1 ohm . . $20 00

The resistance wire is wound on a metal cylinder 7 c. m. in diameter and 10 c. m. long. It is insulated from the cylinder by silk which is shellaced and baked on it. The wire in addition is double silk covered and is shellaced and thoroughly aged by baking at a high temperature after it has been wound on the cylinder. The wire terminals are silver soldered to copper blocks which are screwed and soldered to the heavy copper terminals of the coil. The details of this construction are clearly shown by Fig. 8.

The terminals are given their particular shape so that the coil may be hung by them in mercury cups at the same time that they support it in an oil bath. An outside covering shown cut away in Fig. 8 protects the resistance but is perforated in the sides and bottom with numerous holes to allow free access of oil. A hard rubber top holds all the parts in place.

The resistance wire is wound on a metal cylinder which is made as large as it can be conveniently, so as to allow the maximum possible sur-

face for heat dissipation. Being of metal the heat of the coil is dissipated from the inside as well as the outside surface, and as it is open at the bottom and top the cooling liquid has free circulation both inside and outside.

Experience has shown that ordinary solder has a tendency to crystallize and when used to solder resistance wires to their heavy copper terminals this crystallization makes slight changes in the length of the wire between the terminals. For this reason all of our standards have the resistance wire silver soldered to the copper leads, silver solder having shown itself to be entirely permanent.

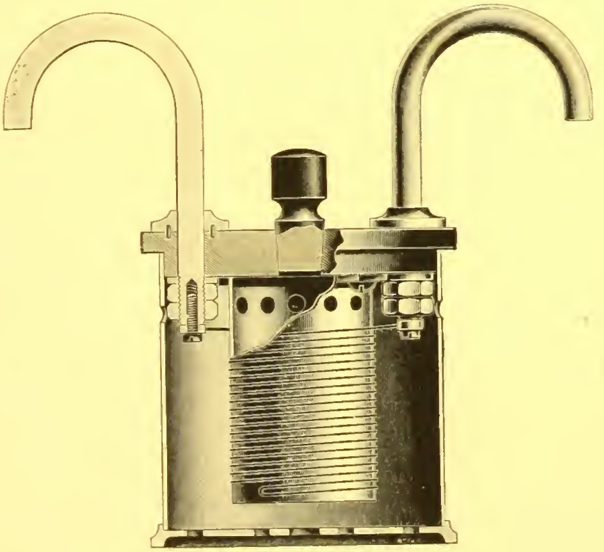
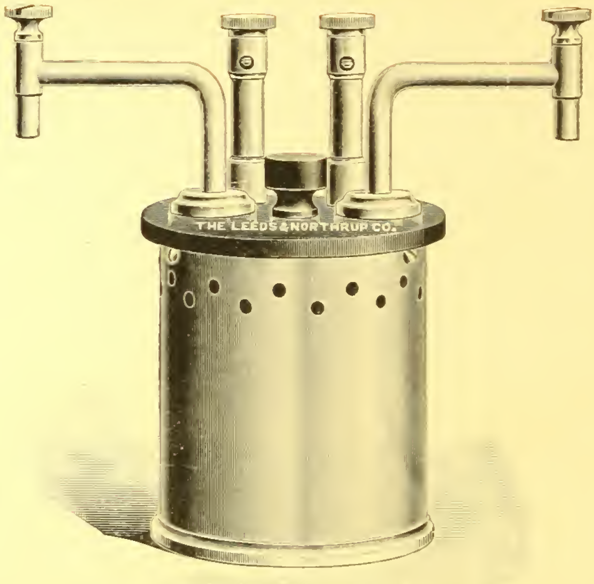


Fig. 8

Standard Low Resistance

4220. Standard Resistance (Reichsanstalt Form) 1 ohm. .$30 00

As the illustration clearly shows these resistances have potential terminals in addition to the current terminals. The binding posts for the potential terminals are mounted on high posts so as to be easily accessible when the standard is immersed in oil. When intended to be used as a resistance standard of precision it should not be subjected to a current of more than 1 ampere. When used as a current standard for lesser accuracy a current of two or three amperes may be used. Both figures are based on the standard being immersed in oil.



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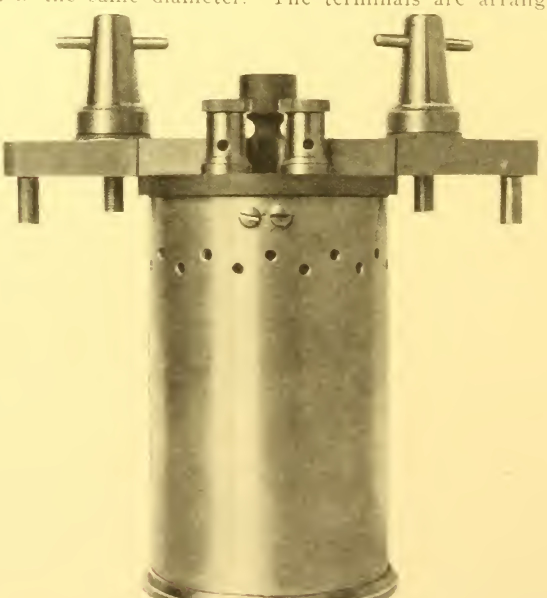
4223. Standard Resistance (Reichsanstalt Form) .001 ohm . $75 00

The case containing the resistances is made longer in this standard, although it is the same diameter. The terminals are arranged so that

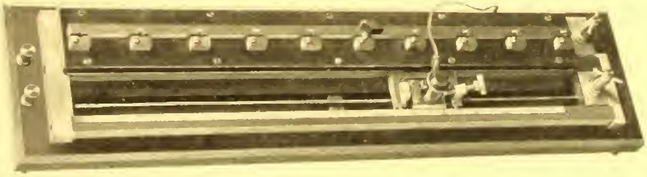


4223

current carrying leads may be clamped on, a special block being provided into which the ends of a cable may be soldered. Immersed in oil, as a precision standard of resistance it has a current carrying capacity of 32 amperes. Used for measuring current to a lesser degree of accuracy it will carry 100 amperes or more.

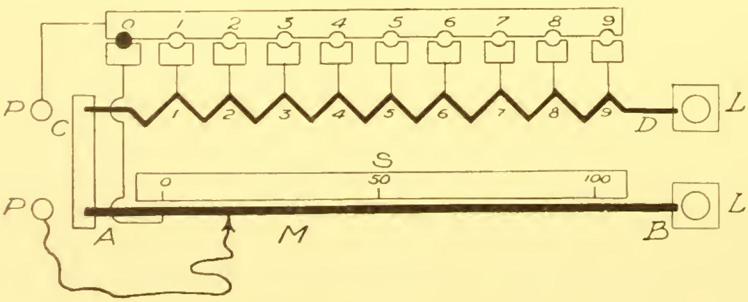
Apparatus for Measuring Low Resistances

The variable standard low resistance and set of ratio coils described below will measure low resistance from .1 ohm down with the same facility and accuracy that an ordinary wheatstones bridge measures high resistances.



4300

The apparatus is based on the principle of the Kelvin double bridge, for a full description of which see our Pamphlet No. 4 on "Standard Resistances." It is novel in that it makes use of a variable standard low resistance instead of a continuously variable set of ratio coils. A careful calculation of the number of accurately adjusted resistances required to measure any resistance from .00001 to .1 ohm to an accuracy of $\frac{1}{25}$ of 1% convinced us that the result could be more economically gotten by using a variable low resistance and a few ratio coils rather than by using a few low resistances and a large set of variable ratio coils. For use in our own laboratory we designed and constructed the instrument described below and we have found it so convenient and satisfactory to use that we have decided to offer it to the public.



4300. Variable Standard Low Resistance..............$210 00

The construction of this variable resistance is shown in the diagram. AB is a heavy piece of resistance metal of uniform cross section and uni-

form resistance per unit of length; CD is another piece of resistance metal of smaller cross section, and the two are joined together by a heavy copper bar AC into which both are silver soldered; LL are the current terminals and PP are the potential terminals. The resistance of AB between the marks 0 and 100 on the scale S is .001 ohm. From the point 1 on the resistance CD to 0 on AB is also .001 ohm, from 2 to 0 is .002 and so on, and from 9 to 100 is .01 ohm. The slider M moves along the resistance AB and its position is read on the scale S which is divided into 100 equal parts and can be read by a vernier to thousandths. Subdivided in this way the resistance between the tap off points PP may have any value from .001 to .01 ohm by steps of .000001 ohm. Using a ratio of 1 to 10 it gives all values from .1 ohm to .01 ohm by steps of .00001 ohm and by using the inverse ratio all values from .001 ohm to .0001 ohm by steps of .0000001 ohm.

In order to make the apparatus available for measuring even very much smaller resistances a tap off is also run to the point 0 on AB so that one connection may be to it and the other to the slider. The resistance between 0 and the slider M will then be the one which comes into the measurement. It cannot of course be known to the same degree of accuracy as the resistances of a higher value but high accuracy is not usually required in the measurement of such resistances as switch contacts, etc., for which this would usually be employed.

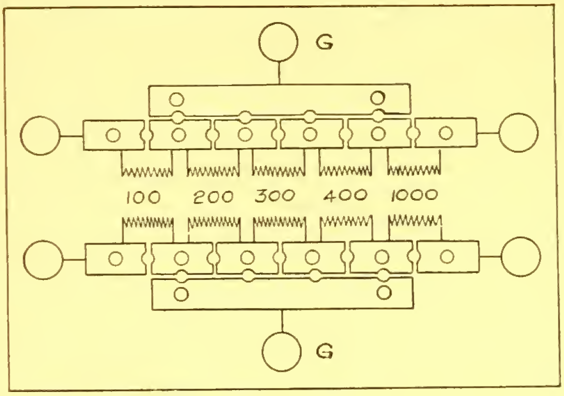
The mounting is very substantial and the workmanship is the best throughout. Great care has been given to the design and construction of the slider. In use it must always be in contact, even when it is being moved; it must always make sufficiently good contact not to appreciably vary the resistance of the ratio coil with which it is in series, and it must do this without wearing away the resistance metal over which it moves. An extended experience with the form of slider which we worked out has shown that these points are satisfactorily covered.

The resistance alloy used has a very low temperature coefficient and a negligible thermo electric force against copper. These qualities coupled with the fact that it is sufficiently large to carry 55 amperes without heating make it available for other purposes than the measurement of low resistances, some of which are described below.

To make resistance measurements with the above standard a set of accurately adjusted ratio coils are necessary. To meet this requirement we have designed the following.

4320. Set of 10 Ratio Coils............................$80 00

For comparing low resistances by the Kelvin double bridge method. These coils are arranged as shown in Fig. 9. With them the following ratios can be gotten: 100 : 200, 100 : 300, 100 : 400, 100 : 500, 100 : 600, 100 : 700, 100 : 900, 100 : 1000, 200 : 1000, 300 : 1000, 400: 1000, 500: 1000, 600: 1000, 700 : 1000, 800 : 1000, 900 : 1000, 1000 : 1000, 300 : 300 and 400 : 400. By having the plugs symmetrically placed in the two arms the ratios will always be the same. The coils for these boxes are wound on our high grade metal spools (see circular No. 1 of Resistance Boxes) and in order that the ratios may remain constant in spite of changes of temperature they are wound from wire having the same temperature co-efficient. The



4320

construction of the box throughout is the same as that of our highest grade resistance boxes. The resistances are adjusted to agree with each other to within 1-100 of 1%.

Method of Using the Variable Standard Low Resistance

The measurement of the resistance of copper conductors for the purpose of determining their conductivity is one of the important uses of

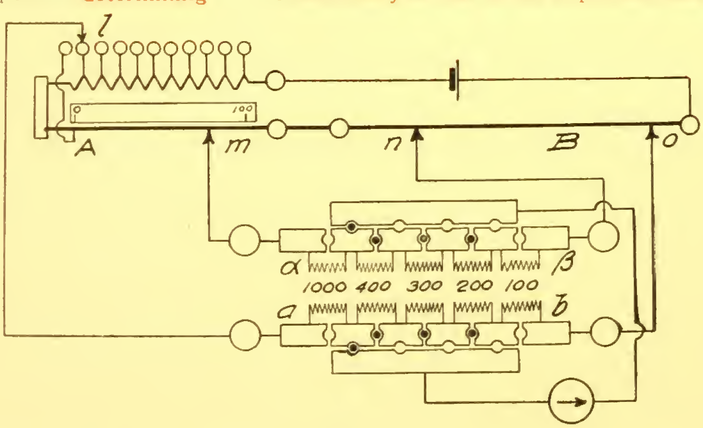


Fig. 9

this apparatus. Since the connections for making this measurement are the same as for other measurements we shall describe and illustrate it.

In the Fig. 9, B represents a short piece of copper wire to be measured. *n* and *o* are two contact points on it at a known distance apart and the connections are made to the battery, the variable standard low resistance and the set of ratio coils as shown. The ratio $\frac{\alpha}{a}$ and $\frac{\beta}{b}$ is made $\frac{1000}{100}$ and consequently the resistance B will be $\frac{1}{10}$ of that in the variable standard. The final balance is gotten by moving the contacts

l and m. If the resistance read on the variable standard is, for example, .001875 the resistance of B is .0001875.

In the measurement of copper and other wires it is very important that the temperature be accurately known and this can best be done by immersing the sample in oil. For this purpose we furnish a suitable tank and wire holder.

Temperature Coefficients

It is a very simple matter to measure resistance temperature coefficients with this apparatus as slight variations in the resistance of B can be easily and accurately followed by moving the slider m.

Current Measurement

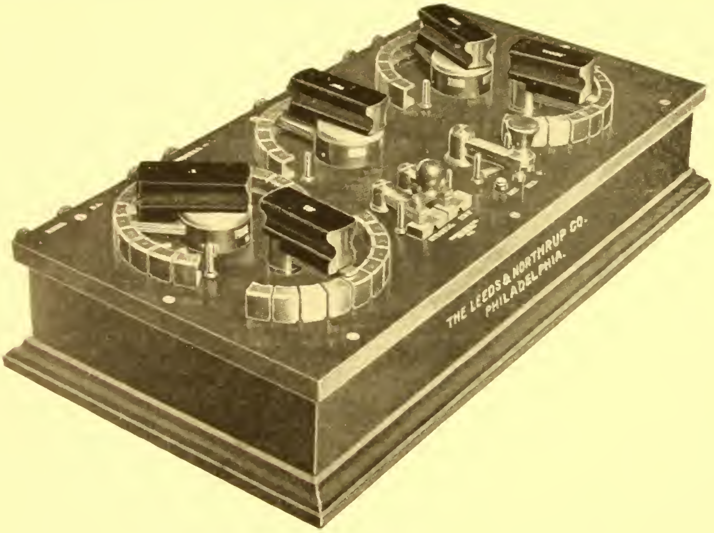
As the Variable Standard Low Resistance will carry 55 amperes it is a very satisfactory standard resistance for measuring current by the potentiometer method. The fact that it is easily variable gives it a wide range and makes it possible to bring the potentiometer reading to the most favorable part of the scale.

With a standard cell, an ordinary resistance box, a galvanometer and an accessory battery it makes a complete outfit for the accurate measurement of currents within its range.

It may also be very satisfactorily used for measuring current in connection with a millivoltmeter or a calibrated galvanometer.

Potentiometers

For complete description of our Standard Potentiometers and accessory apparatus, see our Pamphlet No. 2. This is twenty pages devoted to a critical discussion of Potentiometer design, and a detailed description of our apparatus.



5500

5500. The Leeds & Northrup Standard Potentiometer . . $250 00

4451. Regulating Rheostat for same 65 00

Our standard potentiometer is completely described in our "Pamphlet No. 2 "Potentiometers," to which those interested are referred as space does not permit of repeating it here.

In the design and construction of this instrument we aimed at the following and experience has shown that the aim has been realized in a high degree.

1. The greatest precision of measurement.

2. Facility of manipulation.

3. A direct reading instrument requiring neither calculations nor corrections.

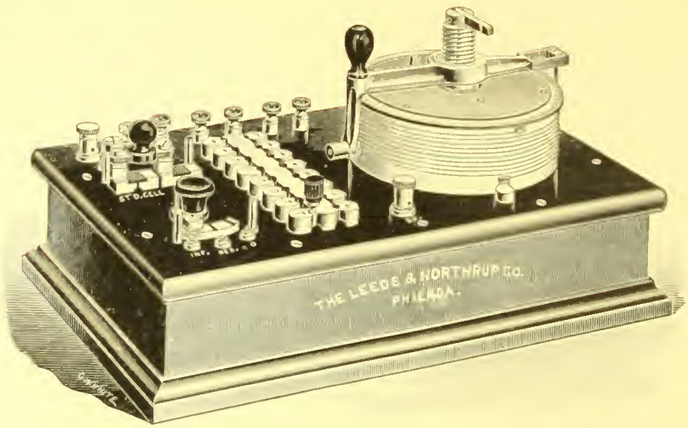
4. An arrangement which makes it possible to verify the accuracy of the resistances with the facilities available in an ordinary laboratory.

We ask particular attention to the following advantages and special features of our design.

The quick method of checking against the standard cell.

The arrangement by which the handle stops so that the brushes are always directly over a block without bridging between them.

The brush construction which absolutely eliminates contact errors.



5555

5555. The Leeds & Northrup Potentiometer, Type K, double range $165 00

The high scale reads from .00001 volt to 1.5 volts.
The low scale reads from .000001 volt to .15 volts.

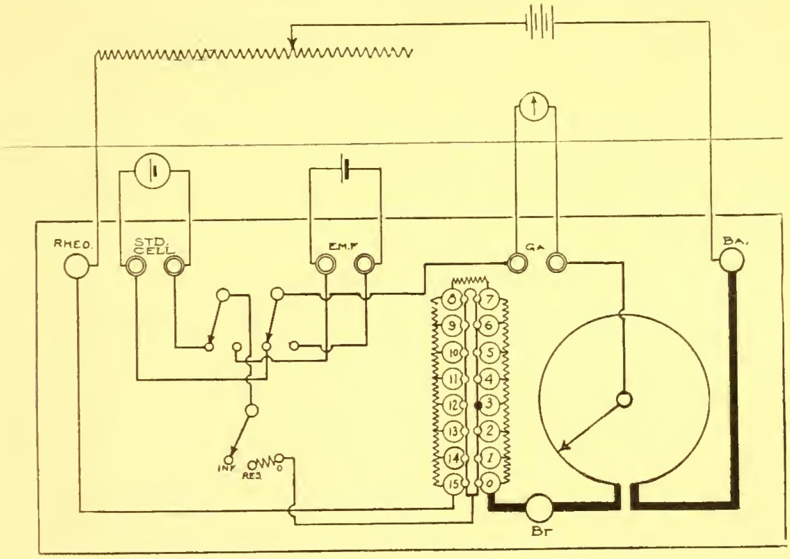
4550. Regulating Rheostat for Potentiometer, Type K . . . $35 00

The Type K potentiometer belongs to the class in which the subdivisions are read on an extended wire. It is characterized by simplicity of design, which makes it easily understood and easily manipulated, and low resistance. These features make it a desirable instrument for many purposes, particularly for measurement where the resistance in the external circuit is low, such as temperature by thermo-couples, or current by the fall of potential across a standard low resistance.

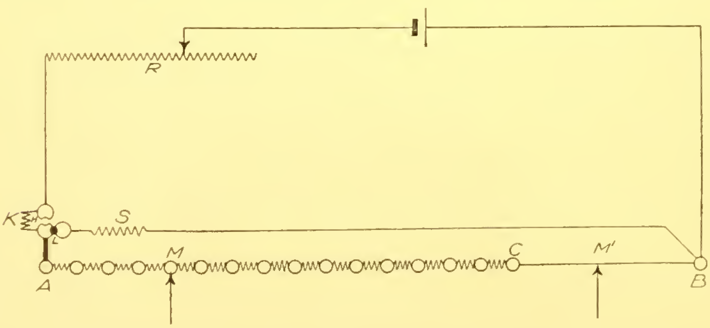
The arrangement will be clear from the diagram and following description:

The extended wire on which the small subdivisions are read takes ten turns around a marble cylinder 6″ in diameter, and is consequently about 190″ long. In series with this are 15 coils, each one of which has the same resistance as the wire. The entire plan of the connections is shown in the diagram, in which, however, the extended wire is indicated by a single turn. A double throw switch throws either the standard cell or the unknown E. M. F. in the circuit containing the galvanometer and the movable points which make contact on the galvanometer wire. A combined key and switch like that used on our standard potentiometer is also in this circuit and by means of it the circuit may be opened, closed through 100,000 ohms, or closed without extra resistance. The extended wire has ten turns and each turn is subdivided into 100 parts. As each division is ¼″ long, and the half is indicated, tenths of a division can be estimated. Consequently the thousandth part of the extended wire can be read directly and the ten thousandth estimated. The positions of the plug, and the contact on the slide wire, indicate the voltage. For instance

if the plug stands, for a balance, at 1.2 and the contact at 1 revolution and $\frac{35}{100}$ the reading is 1.2135 volts. To see that the proper current is flowing through the potentiometer throw the double throw switch on "Standard Cell" and set the plug and moving contact at the positions which indi-



cate E. M. F. of the standard cell (the temperature correction having been made) and adjust the regulating rheostat until the galvanometer shows a balance. To make a measurement throw the double throw switch on "E. M. F." and reset the plug and contact until the galvan-



ometer is again balanced. Their positions then give the desired reading direct in volts.

The construction of the extended wire part of the instrument is exactly the same as that of our Kohlrausch bridge. The contact is movable and the polished cylindrical marble, on which the wire is fastened, is fixed. In this way both ends of the wire have reliable soldered connections out to the binding posts, and the connections in the contact cir-

cuit are also soldered, except that found between the long nut moving on a large screw which moves the contact arm up and down as it rotates. This, on account of its ample size, is entirely reliable. The marble cylinder is 6" in diameter; the wire makes ten turns around it, and the total resistance is exactly 5 ohms. A vertical scale shows the number of turns, and the fraction of a turn is read from a circular scale, which is divided to 200 parts and can easily be estimated to tenths of a division.

The **contact rubs on the wire continually** and has been very carefully designed to make sure that **it will always make a good contact** and that it **will not wear the wire.** It has been thoroughly tested in both of these particulars; in regard to wearing the wire as follows: We connected one of these bridges to a small motor so that the contact would rub backwards and forwards over a length of about 3" of the wire near one end, and allowed it to run 6 hours. During that time it rubbed over the 3" of wire more than 100,000 times. The middle point in resistance on the wire was measured before and after the test, and absolutely no difference could be noted due to the rubbing. The two measurements agreed with each other within 1-500 of 1%. It is accordingly evident that no error from this cause is to be feared.

The above covers only the high scale 1.5 volts to .00001 volt. **The arrangement by which the instrument is given a low scale** was suggested to us by Dr. F. A. Wolff, of the National Bureau of Standards, and is accomplished by the addition of two resistances. It is illustrated in the diagram in which AC represents the 15 coils of the potentiometer wire and BC the extended portion. M and M^1 are the contact points between which the E. M. F. is read. R is the regulating rheostat. With a plug in the position H the arrangement is exactly that described above for the high scale reading. In the position L it is set for the low scale reading. The potentiometer wire AB is shunted by the resistance S which makes it exactly $\frac{1}{10}$ what it was before, and the coil K thrown into the circuit is of such a value that the total resistance remains constant. The current flowing will consequently remain the same, but the resistance between A and B being reduced to one-tenth of its previous values the electro motive forces read between M and M^1 will also be one-tenth.

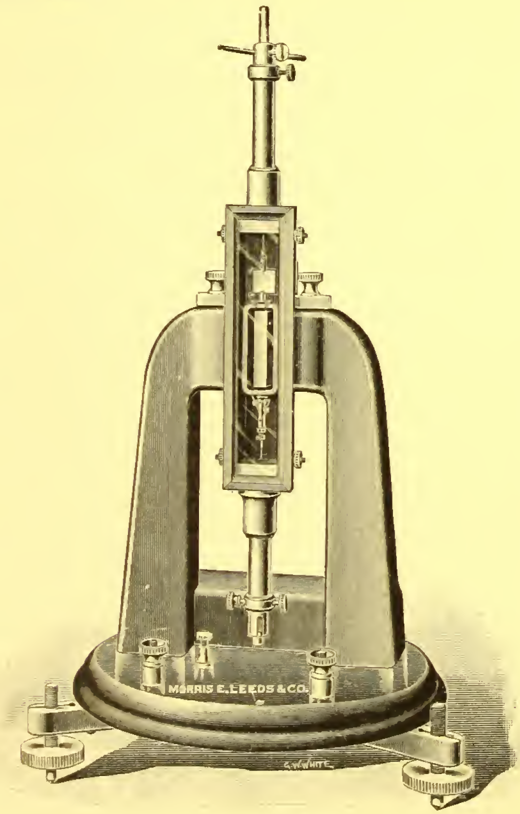
5580

5580. Volt Box $35 00

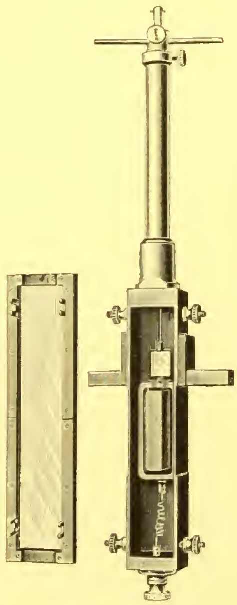
For use with the potentiometer for measuring voltages up to 15 and 150 volts.

D'Arsonval Galvanometers

See our Pamphlet No. 3 on "Moving Coil" Galvanometers for a general discussion of the principles underlying the design of these instruments and very complete description of the instruments which we make.



2250 with 2254



2252

2250.	D'Arsonval Galvanometer, Type M, without tube and coil	$25 00
2252.	Type S Tube and Coil for same	35 00
2254.	Type M Tube and Coil for same	85 00

The magnet No. 2250 is made by a special process and is unusually powerful. It is arranged so that it will take either of the tubes 2252 or 2254, which are made interchangeable and any number may be furnished with a single magnet or be procured afterwards.

Both of the tubes are designed with a view of having the system exposed to view and easily accessible. Ample clearance is allowed so that it is a simple matter to level the galvanometer. The glass front comes off easily to allow access to the coil. By means of a simple device the coils may be clamped when not in use. These galvanometers are practically free from zero shift and unless otherwise specified are wound so as to be quick in action and dead beat.

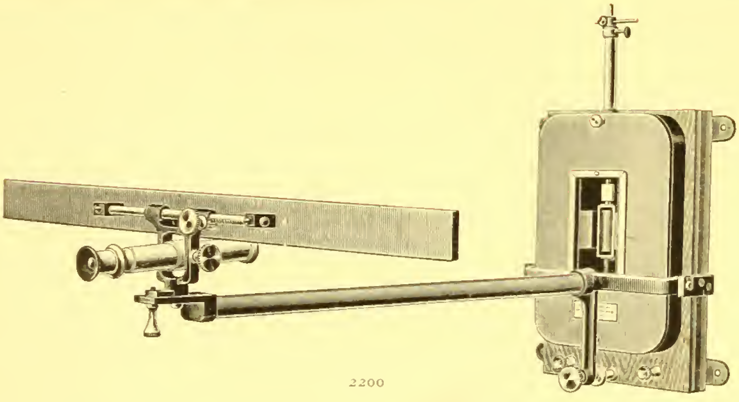
Furnished with a Type M tube, No. 2254, the instrument becomes a marine galvanometer and is designed primarily for use on shipboard. By suspending the coil between straight, stretched, upper and lower suspensions, and carefully balancing it, it is made so that a 30° inclination of the instrument will not cause a deflection of more than 3 scale divisions when the scale is at a distance of 1000 scale divisions from the mirror. The sensibility of a galvanometer meeting the above conditions with a resistance of 1000 ohms is from 10 to 20 megohms. It is exceedingly quick in action, has an absolutely positive zero and may be made so dead-beat as to return absolutely to rest, when given a full scale deflection, within 3 seconds. For many uses on land a galvanometer like this is very valuable. Where it is not necessary that it should stand so great an inclination less heavy suspensions may be used and the sensibility thereby increased to 50 or 100 megohms without altering the action of the galvanometer in other particulars. These balanced coils are not at all influenced by tremors or vibrations.

The suspensions are so strong that the instrument can be carried around without fear of breaking them and the galvanometer does not have to be leveled when it is used. It can be used in many situations as a millivoltmeter and will have a vastly greater sensibility. The constant will remain very permanent, and the deflections will be proportional to steady currents or to the quantities of electricity suddenly discharged through the coil.

The marine galvanometer is an ideal lecture room instrument.

Note.—The galvanometer as described above is our regular form, catalogued on page 16 of our general catalogue. The instrument at the exhibit of the National Bureau has had several useful additions and accessories to adapt it to the various general uses of a large testing laboratory. The galvanometer and its accessories are provided with an oak case in which they can be packed and easily transported. The accessories consist of an optical system, which fits directly upon the galvanometer frame, and which serves the purpose of a telescope and scale directly attached to the instrument. This optical system can be readily removed and the galvanometer used with an ordinary telescope and scale. A plano-convex lens is fastened at one end of the galvanometer window. When this end of the window is uppermost the lens comes in front of a plane mirror, with which two of the extra coils furnished are provided, and the galvanometer is then adapted for use with a lamp stand and scale. A useful accessory is a small box which contains several tools for replacing suspensions, and for balancing the marine coil. It also contains two sets of extra marine suspensions, and several upper and lower suspensions for use in the high sensibility tube. In this box are also contained the two extra coils provided with plane mirrors.

A laboratory possessing a galvanometer outfit of the above character, would be provided with a single instrument which would fill nearly every requirement of galvanometer work.



2200

2200. Wall D'Arsonval Galvanometer, Type H........ $45 00

A galvanometer in order to satisfactorily meet its requirements must first of all have ample sensibility for the particular work for which it is intended. After that, it should be quick in its action so that the user will not waste time while it is returning to its zero position; it must have a positive zero, so that there may be no question about reading small deflections and determining the value of deflections. Unless it is to be used as a ballistic instrument, it must be dead-beat, and finally it must be arranged so that it can easily be set up and so that suspensions can be readily replaced when they are broken. It has been very generally assumed that many of these good qualities could not be expected of the D'Arsonval Galvanometer, in spite of which it is very widely used on account of its freedom from magnetic disturbances and its general robustness compared with other types. Its pronounced advantages in these respects led us to make an extensive experimental study of the instrument with a view of improving it in the other particulars above mentioned. Our experiments have enabled us to design instruments which are highly satisfactory from all standpoints and are very great improvements on previous types. For measuring resistance by the Wheatstone bridge method or by the Kelvin double bridge method, for use with potentiometers, for the measurements of condenser capacities, etc., etc., our galvanometers Types H & M will be found not only amply sensitive but so quick in action and dead-beat that the operator's time will not be taken up waiting for the galvanometer to reach a deflection or come to rest. They have such a positive zero that small fractions of a scale division can be estimated with certainty, and they are arranged so that the working parts are easily accessible and suspensions, etc., can be readily replaced.

In both of these types of galvanometers, the design is such that the moving parts can be seen and the galvanometer easily leveled. The leveling is further facilitated by allowing the coil ample clearness.

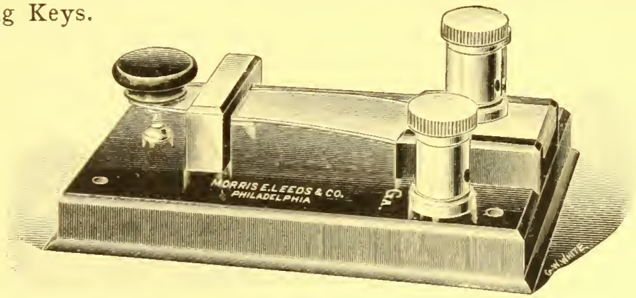
2301

2301. Portable D'Arsonval Galvanometer with Calibrated Scale $20 00

This galvanometer is the same form as that used in our portable testing sets, but is mounted in a box with rubber top and two binding posts. The coil is circular in form, turns over an iron core, and is mounted upon jewels. It is very sensitive for a galvanometer of this type, is thoroughly well made and the pivoted system has exceedingly small friction. The current due to one volt through 1 megohm will cause the pointer to move about 1 mm. over the scale. The pointer can be adjusted to zero from the outside of the case and the coil is so well balanced that the galvanometer can be used in an inclined position. This instrument will be found very useful in all places where a sensitive, portable detector galvanometer is required. The scale over which the pointer moves is calibrated for 10 divisions each side of the zero, so that up to this limit the galvanometer will serve as a measuring instrument when its constant has once been determined.

Keys

Our Pamphlet No. 7, "High Grade Keys for Electrical Testing," contains detailed descriptions of our line of keys and valuable information in regard to the best method of constructing Electrical Testing Keys.



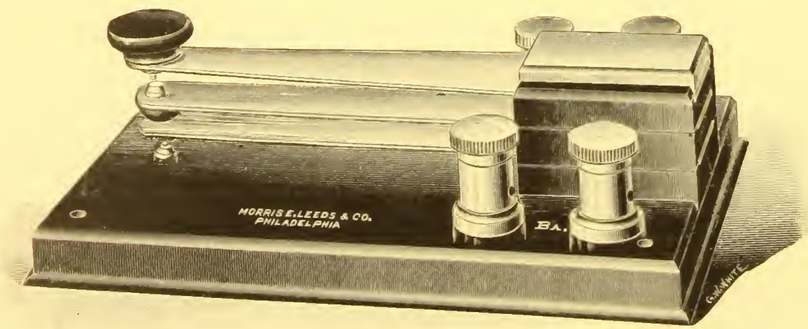
5100

5100. Short Circuiting Key.......................... $6 00

This key is intended especially for use with D'Arsonval galvanometers used with zero deflection methods. The key is connected in circuit with the galvanometer so that whenever the key is not depressed, the galvanometer is short circuited, and its oscillations are quickly damped out by the currents induced in its coil. The back end of the spring is held in a slot in a rubber block, and this is held in a slot milled in the base. By this construction the **perfect matching of the contacts is always secured.**

5105. Short Circuiting Key, with Catch................ $8 00

This key is the same as 5100 described above, but has a catch with which the spring may be depressed and the battery contact circuit kept closed.

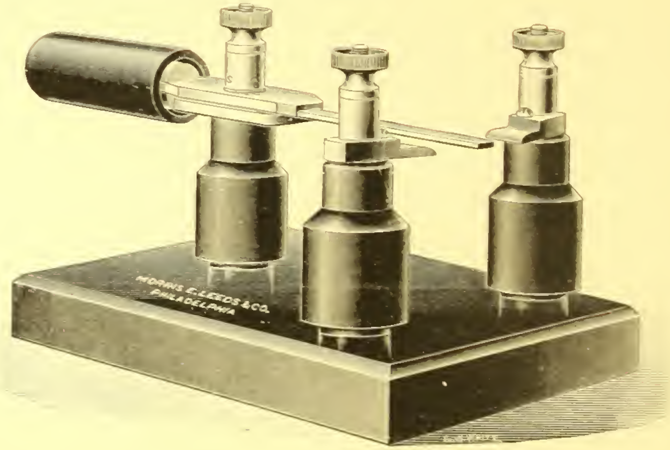


5110

5110. Double Contact Key.......................... $10 50

It will be noted that the same method for holding the springs is used

in the design of this key as in the short circuiting key, the method being extended to the base and three blocks.

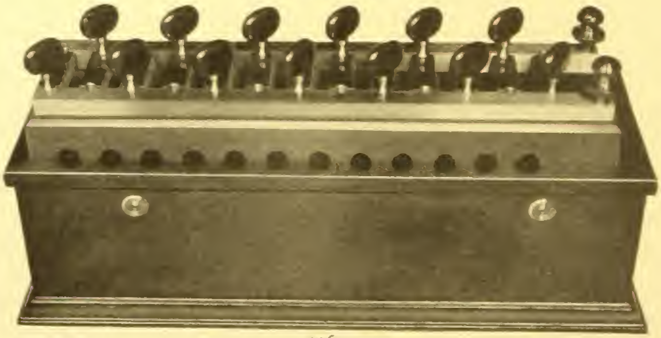


5290

5290. Charge and Discharge Key $17 50

This key is admirably adapted to charging and discharging condensers of small or large capacity. The insulation is very high, so that no electricity can be lost by leakage. The insulated handle enables the key to be used without insulating the body.

Condensers



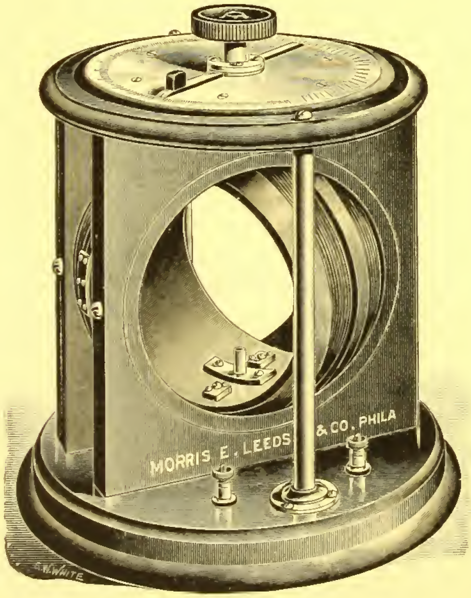
1060

1060. 1 Micro-farad $200 00

Subdivided into twelve sections 0.001, 0.002, 0.002, 0.005, 0.01, 0.01, 0.02, 0.05, 0.1, 0.1, 0.2, 0.5 M. F. By simple combinations all values can be gotten from 1 M. F. to 0.001 M. F. by steps of 0.001 M. F. The condensers are connected between the cross bars and may be connected in series or parallel or in combinations of the two. All of the blocks are insulated on independent pieces of hard rubber and the condenser segments are thoroughly insulated inside of the box.

Self-Induction Apparatus

Our line of Self-Induction Apparatus is represented by the two pieces described below. Our complete line is described in Pamphlet No. 8, which contains also valuable information in regard to making Self-Induction measurements.



5316

5316. Ayrton & Perry's Variable Standard of Self-Induction $125 00

As shown in the illustration this instrument consists of two coils wound on sections of concentric spherical surfaces, the inside one of which can be rotated with reference to the outside one, and thus their co-efficient of induction varied without changing their resistance. As it is very important that the shape of the coils should not change, the instrument is built up of very carefully selected and thoroughly seasoned wood, and is made of a large number of pieces put together so as to prevent warping. The scale is divided to read in millihenrys on one side and in degrees on the other. Its range is approximately from 3.5 to 42 millihenrys. Special attention has been given to the connections between the inside and outside coil, and as now made there are none but soldered joints, and all the connections are exposed to view, so that they can be easily inspected or replaced.

5319. Standard of Self-Induction 100 Millihenrys...... $90 00

This is subdivided into 10, 20, 30 and 40 millihenrys. The coils are mounted in a single box and their terminals are brought out to blocks which are connected by plugs as in a resistance box. They may be used one at a time or two or more in series, in which case the co-efficients of self-induction are added like resistances. The coils are carefully arranged so as to avoid mutual induction. Non-inductive resistances are also provided and arranged so that when a spool of self-induction is cut out a non-inductive resistance of equal value and of wire having the same temperature co-efficient is put in circuit, and thus the resistance of the box is always the same, while the inductance is varied.

Description of the Rosa Curve Tracer

One of the most interesting and fruitful methods of study of alternating current phenomena is the tracing of the forms and phases of alter-

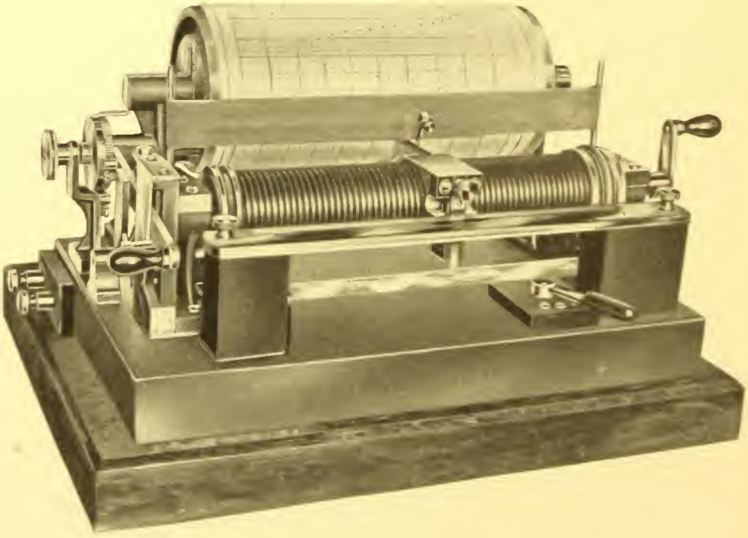


Fig. 1

nating current waves. Without these curves one can gain only an inadequate idea of the inner workings of a dynamo, motor or transformer. And considering the rapid multiplication of alternating current apparatus, both of single phase and multiphase varieties, it is evident that the field of usefulness of alternating current diagrams, already very great, is constantly increasing.

The practicability of this method of investigation and testing has been seriously limited by the great labor of obtaining the curves, and the insufficient accuracy of the curves when obtained. What is wanted is a

continuous line or so large a number of points as to be practically equivalent to a continuous line, marking exactly the fluctuations of the current, electromotive force or power, as the case may be. And when several such related curves have been drawn to scale on a single sheet, showing the forms, phases and relative amplitudes of the current and electromo-

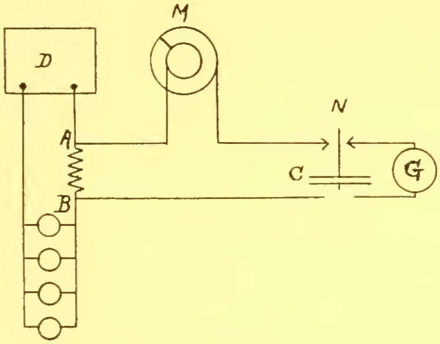


FIG. 2

tive forces (and also perhaps the magnetizations and power waves) which are concerned in the operation of a given machine or system, we have an elegant representation of what is transpiring within the machine or system.

Various methods of obtaining these curves have been used. An instantaneous contact-maker, connected with the armature of the dynamo,

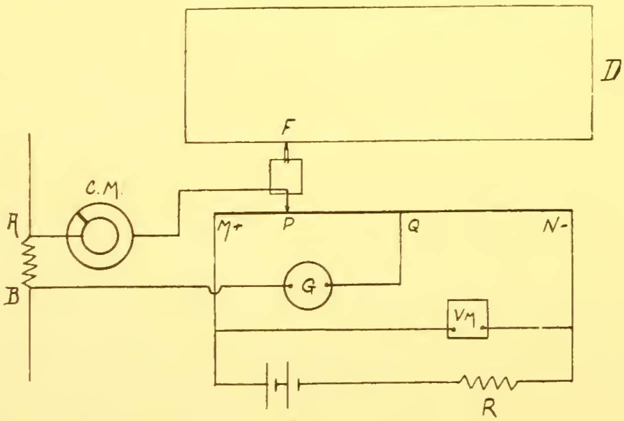


FIG. 3

is frequently employed (Fig. 2). The value of the current, at the instant the circuit is closed at M by the contact-maker, may be determined by measuring the difference of potential of the terminals AB of a known resistance, through which the current flows. The potential difference is sometimes ascertained by joining a condenser (C) to AB by a switch (N),

and then discharging the condenser through a ballistic galvanometer. The position of the contact brush is then advanced, the condenser is again charged and discharged, and a second value of the current, corresponding to the new phase of contact, is obtained. Or an electrometer may be substituted for the galvanometer, and its deflection read at each setting of the brush. In this way a number of points may be obtained and plotted out on cross-section paper, and a curve drawn through them. But if the number of points is sufficient to give an accurate curve, the time and labor required are very great.

With the Rosa curve tracer the most laborious parts of the operation (setting the contact brush, taking, recording and reducing the readings and plotting the curve) are done by the machine automatically, and the work of several hours may be done in as many minutes. The measurements are made by a null method, using the principle of the potentiometer, the results are plotted by the machine more accurately than they could be plotted by hand, and a curve being obtained in a few minutes, the

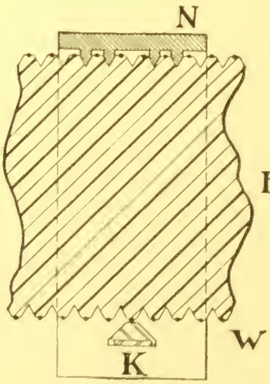


Fig. 4

speed, voltage and other circumstances may be maintained more nearly constant than would be possible when the observations extend over several hours. For these reasons the curves obtained are more accurate than any ever before published.

The method of the curve tracer is illustrated in Fig. 3. A hard rubber cylinder is wound with a single layer of bare wire. A constant current from the battery, consisting of one or two small storage cells, passes through this spiral causing a uniform fall of potential from M to N. A voltmeter is joined across the terminals and the voltage maintained constant by varying the adjustable resistance R when necessary. The current to be delineated passes through the non-inductive resistance AB. We have to measure the instantaneous values of the potential difference of the terminals AB at successive instants throughout the period of a wave. B is joined through the galvanometer to the middle point, Q, of the spiral MN. A is joined through the revolving contact maker to a sliding contact P. If the current in AB were a direct current the contact maker would of course be unnecessary; if it is alternating, and the con-

tact maker is joined to the shaft of the generator or is driven synchronously with it, then every time the contact is made at any particular phase of the wave, the current has the same value and in general the galvanometer will show a deflection. When, however, the traveling contact P is so adjusted that the galvanometer deflection is zero, the potential difference between P and Q is then the same as that between A and B. This is proportional to the distance PQ, and is positive on one side and negative on the other side of Q. The distances PQ could, therefore, be used as ordinates, and the corresponding positions of the contact brush taken as abscissas, and a curve of current plotted as usual.

To avoid the labor of reading, recording, reducing and plotting by hand the various values of the current and electromotive force which go

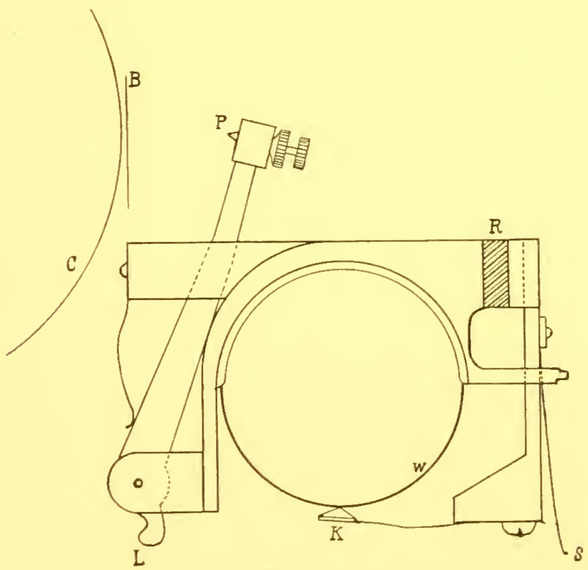


Fig. 5

to make up the curves of these quantities, the instrument is so arranged that as soon as any instantaneous value of the current or voltage has been balanced against the potentiometer coil its value is immediately printed on a sheet of cross-section paper mounted on a cylinder the axis of which is parallel to the potentiometer. This is done in a manner indicated by Figs. 4 and 5.

The hard rubber cylinder carrying the potentiometer wire has a double thread, as shown by Fig. 4. In the deeper of the two threads a brass half nut N rests, while the wire W is wound in the shallower thread. The threads of the half nut do not touch the wire at any point, but a contact piece, K (Figs. 4 and 5) which is carried by a spring and insulated from the nut by the hard rubber piece, R, rests on the wire and as the cylinder is turned and the nut travels along the thread, the contact piece makes a sliding contact along the wire.

When the galvanometer deflection has been brought to zero by moving the contact K to such a point that the difference of potential PQ is equal to that between A and B, the printing lever is lifted and a bar strikes the short arm L and throws the printing point P against the typewriter ribbon B and so prints a point on the paper which is mounted on the cylinder C. Dropping the lever causes the cylinder to advance by means of a ratchet and pawl, the amount of this advance being adjustable by placing the stop at such a point that one, two, three or more teeth of the ratchet are engaged by the pawl at each throw of the lever. The paper is now in position for the next point, and this is printed as soon as the galvanometer deflection is again brought to zero by moving the traveling contact one way or the other as before.

The galvanometer is a quick, dead-beat D'Arsonval, and settings are made very rapidly. The moving contact and printing point are attached to the traveling nut, as already stated. The observer keeps his eye fixed upon the galvanometer scale; with his right hand he turns the handle at the end of the cylinder, which causes the nut to travel to and fro, and with his left he works the contact key. As soon as the latter is opened, the brush advances, and the spot of light goes off the zero, to the right or left, according as the current has decreased or increased. The contact P is immediately moved in the same direction, until the spot of light is brought back to zero, when the circuit is again closed, a point is printed, the spot of light again goes off the zero, and so on. Twenty points a minute can be printed after some practice. Typewriter ribbons of different colors are used for different curves, so that the curves are easily distinguished, even though they be considerably interlaced.

The Contact Maker

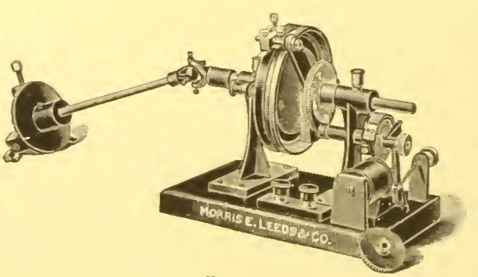


FIG. 6

The contact maker shown in Fig. 6 is directly connected to the generator or may be driven by a synchronous motor. In the latter case the curves would not be quite accurate if any departure from strict synchronism occurred. A disc of hard rubber mounted on the shaft revolves at the same angular speed as the generator, if they are directly connected. A contact piece of steel is let into the edge of this disc and a steel spring bearing on the edge makes a short contact at every revolution. For a four-pole alternator two such contact pieces may be used, 180° apart; for a six or a twelve-pole machine three contacts 120° apart; for an eight or sixteen-pole machine four contacts 90° apart, etc. In practice six con-

tacts are so placed in the edge that the proper number may be used in any case according to the number of poles of the machine. There are two binding posts joined to two brushes on the contact maker which serve as points of entrance and of exit of the galvanometer current. At the moment of balance, when the galvanometer current is zero, no current is passing through the contact and, therefore, the position of balance does not depend on the precise duration or the resistance of the contact.

An electro-magnet at the side serves to actuate the lever which through a ratchet and pawl advances the brush of the contact maker; and this is done automatically when the lever is lifted which prints the point on the cross-section paper. That is to say, the same stroke which prints the point closes a circuit which advances the contact. This advance may be one, two, three or more teeth of the ratchet at a step, according to the position of the stop; that is, a long or short step may be taken as required.

The teeth of the ratchets of the contact-maker and record cylinder are both numbered so that the contact brush and record paper may be set at any position desired. In drawing a curve their initial positions are noted, and when the curve is finished (supposing it represents the electromotive force of the dynamo) the contact brush and record cylinder are turned back to their original positions, the switch thrown so as to join the potentiometer to the primary current circuit (let us say) and the primary current curve is drawn; perhaps then, the secondary current is drawn. The difference of phase of these quantities will then appear from their relative positions on the cross-section paper.

The non-inductive resistance AB, Fig. 3, is adjustable so that any given current may be drawn to a suitable scale which is chosen in advance. For example, currents are drawn to a scale of 1, 5, 10, or any desired number of amperes per centimeter, or per inch, and similarly electromotive forces with 50, 100, 500 or any desired number of volts per centimeter or per inch. So also power curves, magnetic induction curves and hysteresis curves are drawn to a known scale.

Magnetic induction curves are not drawn directly, but are derived from the electromotive force curves. Writing down from the curve the instantaneous values of the electromotive force, and summing them up, we get a series of values of the induction which are laid off upon a strip of paper. This is placed upon the curve tracer, and the curve of magnetic induction printed on the record sheet, showing its proper phase relation to the other curves.

Hysteresis curves are derived from the curves of current and magnetic induction already made, and include the eddy current loss with the hysteresis loss. The curve of current which has magnetized the iron under investigation is printed on a narrow strip of paper, and attached to the end of the record cylinder, at right angles to its position when printed. Two persons are required. One sets the pointer attached to the carriage upon the first point of the strip of the induction curve, while the other, taking the ratchet-wheel in his left hand, sets the cylinder so that the first point of the current curve comes directly under a fixed line above the cylinder. A point is then printed on the record sheet, when the two operators advance to the second points, print a second dot, and so on. The result is a closed hysteresis curve.

Power curves, like curves of current and electromotive force, are drawn directly, while the generator is running. A second potentiometer coil similar to that on the curve tracer also has a sliding contact. This potentiometer is in series with a non-inductive resistance R^1, Fig. 7, and carries a current proportional to the electromotive force, the terminals T being joined to the dynamo terminals, or to the terminals of the circuit of which the power curve is to be drawn. Instead of using a fixed resistance AB, as in other cases, the resistance whose terminals are AB is varied, being in each case proportional to the current at the instant of contact. This is effected by having B fixed at the middle of M^1N^1 and moving A to such a point on the spiral that the distance AB is proportional to the instantaneous value of the electric current, which should have been previously drawn. When the current is negative, A is on the right-hand side of B. The difference of potential between AB is proportional to the distance AB, and also to the current passing through the spiral M^1N^1. Since the former is proportional to I (the current), and the latter is proportional to E (the electromotive force), the difference of potential AB, and, therefore, of PQ, is proportional to the product IE, which is the power. Advancing the contact brush gives a contact at a later instant of the phase, when both I and E have changed. Setting the contact A to the new value of the current and moving P until a balance is obtained, a second point of the power-curve is obtained. Obviously, the power curve will cut the zero line whenever the current is zero (for then A comes to B), and also whenever the electromotive force is zero (for then there is no current in M^1N^1). It has a positive loop when current and electromotive force are both positive or negative, and a negative loop when only one is negative. Thus are power curves accurately drawn to a predetermined scale, and the labor of multiplying the corresponding ordinates of current and electromotive force is avoided.

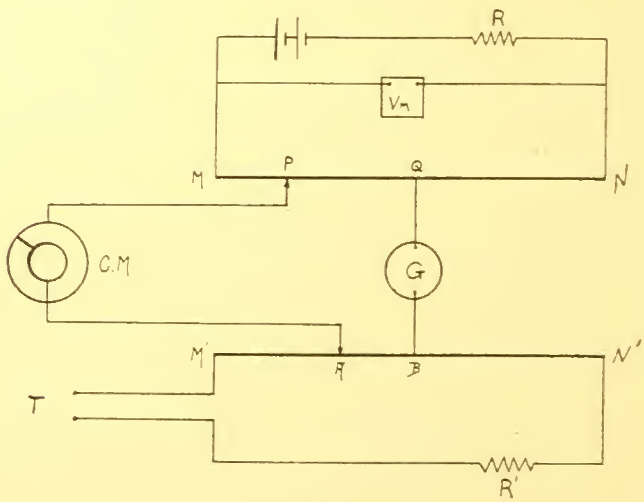


FIG. 7

This form of curve tracer is especially suited to purposes of instruction and of research, where accurate delineations of alternating current curves are desired and where the current and voltage can be maintained constant, for a few minutes at least. Some form of oscillograph is better adapted to studying effects which are not regularly recurring, or where a contact maker cannot be employed.

A full account of the earlier form of the Rosa curve tracer will be found in the "Physical Review" for January, 1898, together with a number of curves not here shown. The instrument was first described at the Buffalo meeting of the American Association for the Advancement of Science, in 1896, and at the Toronto meeting of the British Association for the Advancement of Science, in August, 1897.

The Curves shown on the following pages are accurately reproduced from Curves drawn on the Rosa Curve Tracer

Plate I

Curve I is the electromotive force, showing ripples due to harmonics. The prominent harmonics in this curve are two of thirteen and fifteen times the frequency of the fundamental respectively. Scale of the original curve, 1 inch = 81 volts.

Curve II is the current due to this electromotive force flowing through a coil having large inductance and small resistance (without iron core). Scale of original curve, 1 inch = 2 amperes.

Curve III is a power curve, with a positive and negative loop for every half wave of the electromotive force and current. The power is zero when the curve is zero and also when the electromotive force is zero, as the curve shows. The negative loop is nearly as large as the positive, and the current lags nearly 88° behind the electromotive force. The current is almost entirely free from harmonics, due to the large inductance of the circuit.

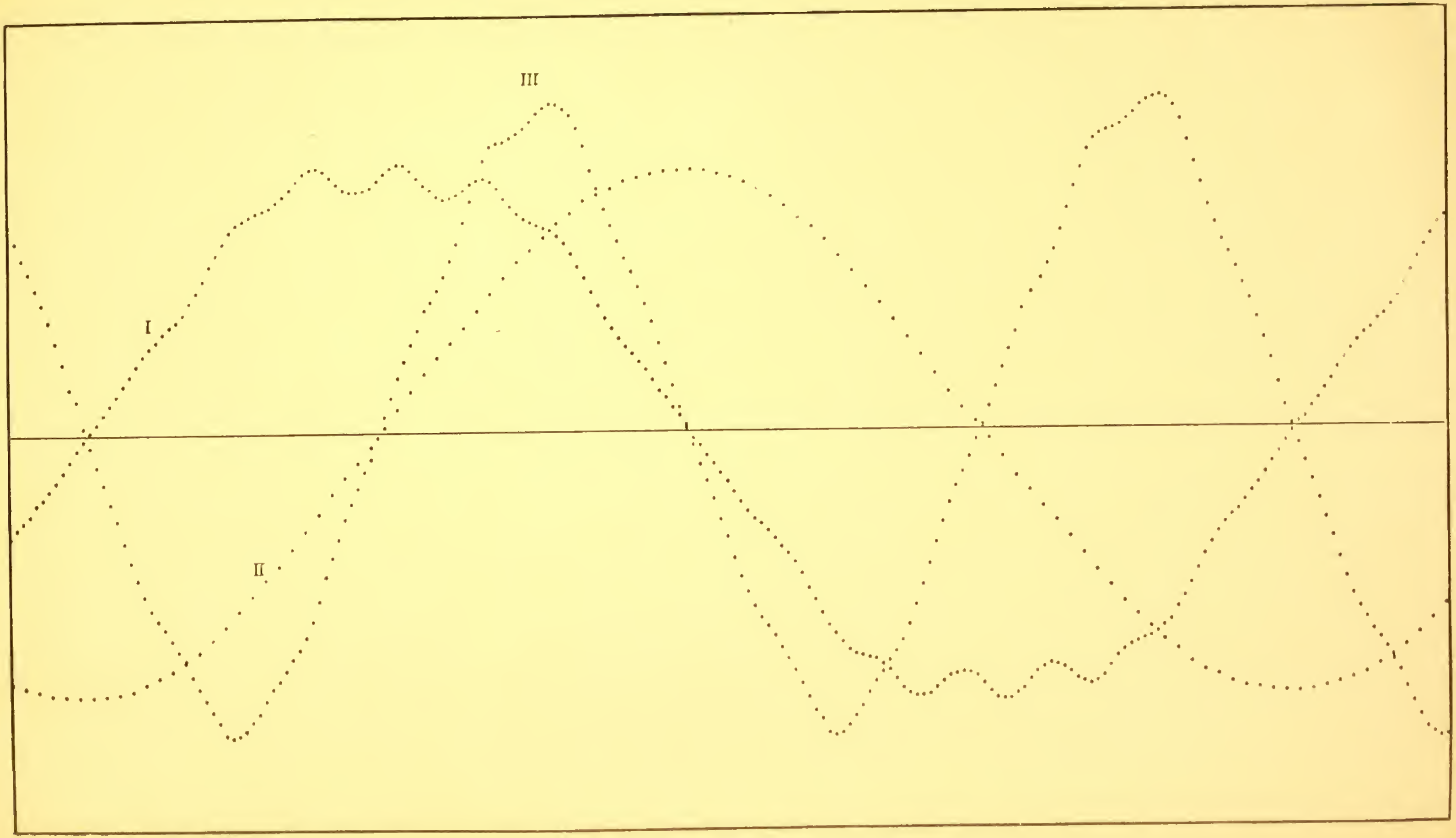


Plate I

Plate II

Curve I is the electromotive force of the same alternator giving the curve of plate 1. A condenser of 21 microfarads is joined to the terminals of the alternator, and this condenser current reacts on the armature, strengthening the harmonics.

Curve II is the secondary electromotive force in a transformer, of which Curve I is the primary electromotive force.

Curve III is the magnetising current of the transformer; that is, the primary current with no load on the secondary. Ripples on this curve are due to the harmonics in the impressed electromotive force.

Curve IV is the magnetic induction. Ripples along the sides of this curve correspond to the harmonics in the electromotive force. The electromotive force is proportional to the slope in this curve, and changes in the electromotive force are due to changes in the slope of the induction curve.

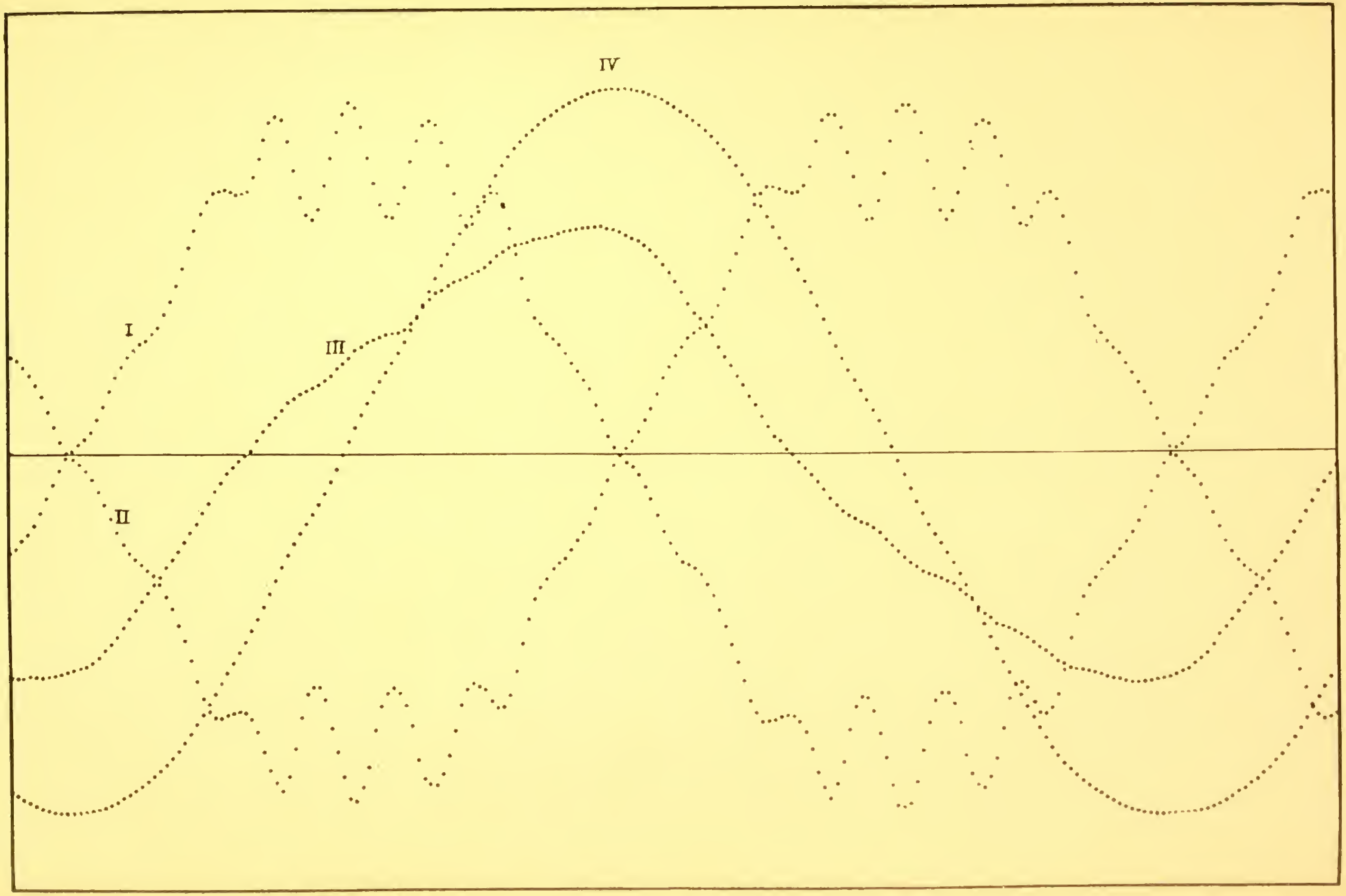


Plate II

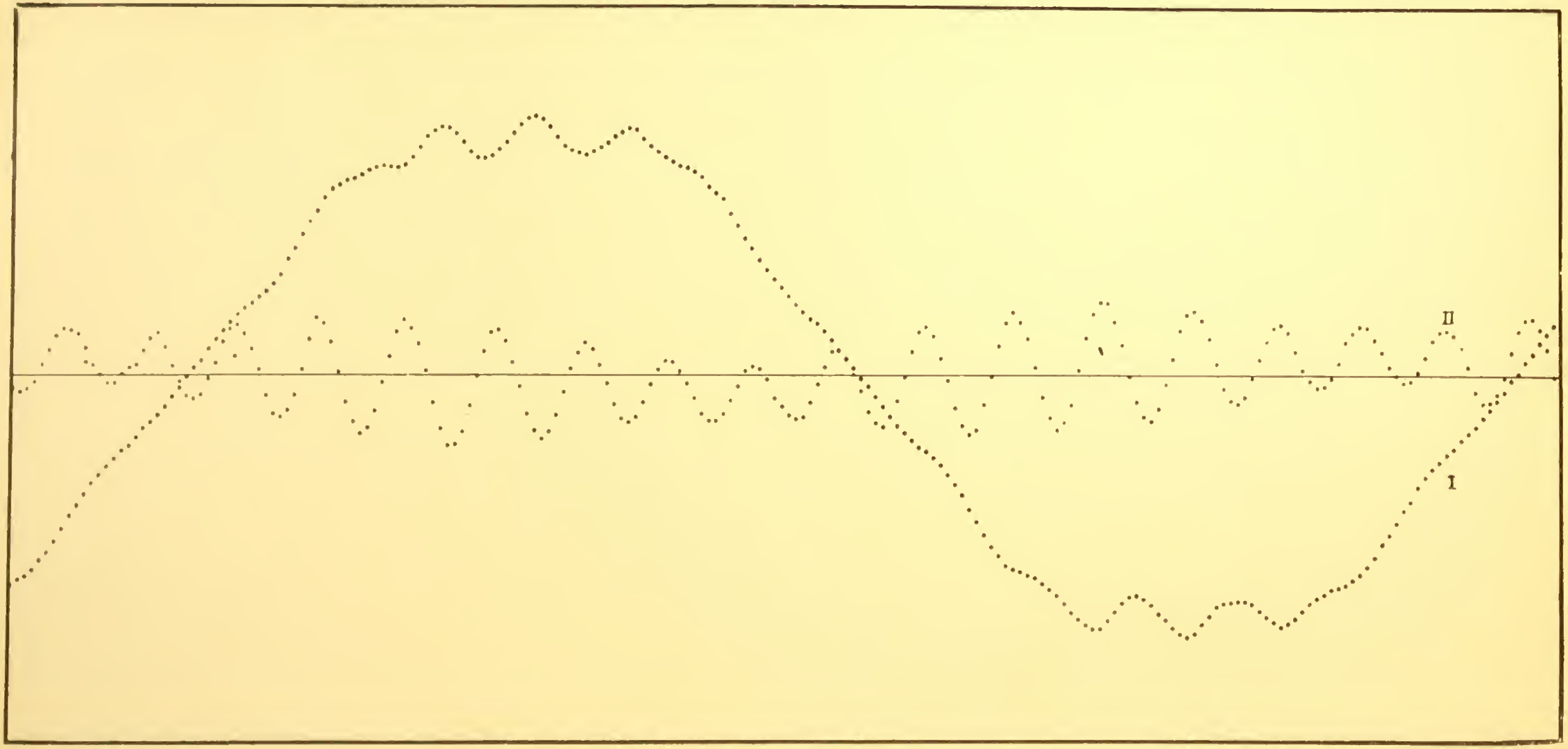


Plate III

Curve I is the electromotive force of the alternator, same as in Curve I, Plate 1.

Curve II is the current flowing through a condenser, on which this electromotive force is acting. A Siemens' Dynamometer, in series with the condenser, has some self-inductance. This is a striking example of resonance, the value of the inductance and capacity being such as to produce resonance for the fifteenth harmonic in the electromotive force. The frequency of the fundamental was 140 per second; therefore the frequency of the harmonic for which resonance occurs is 2100 per second. The harmonic current is much larger than the fundamental.

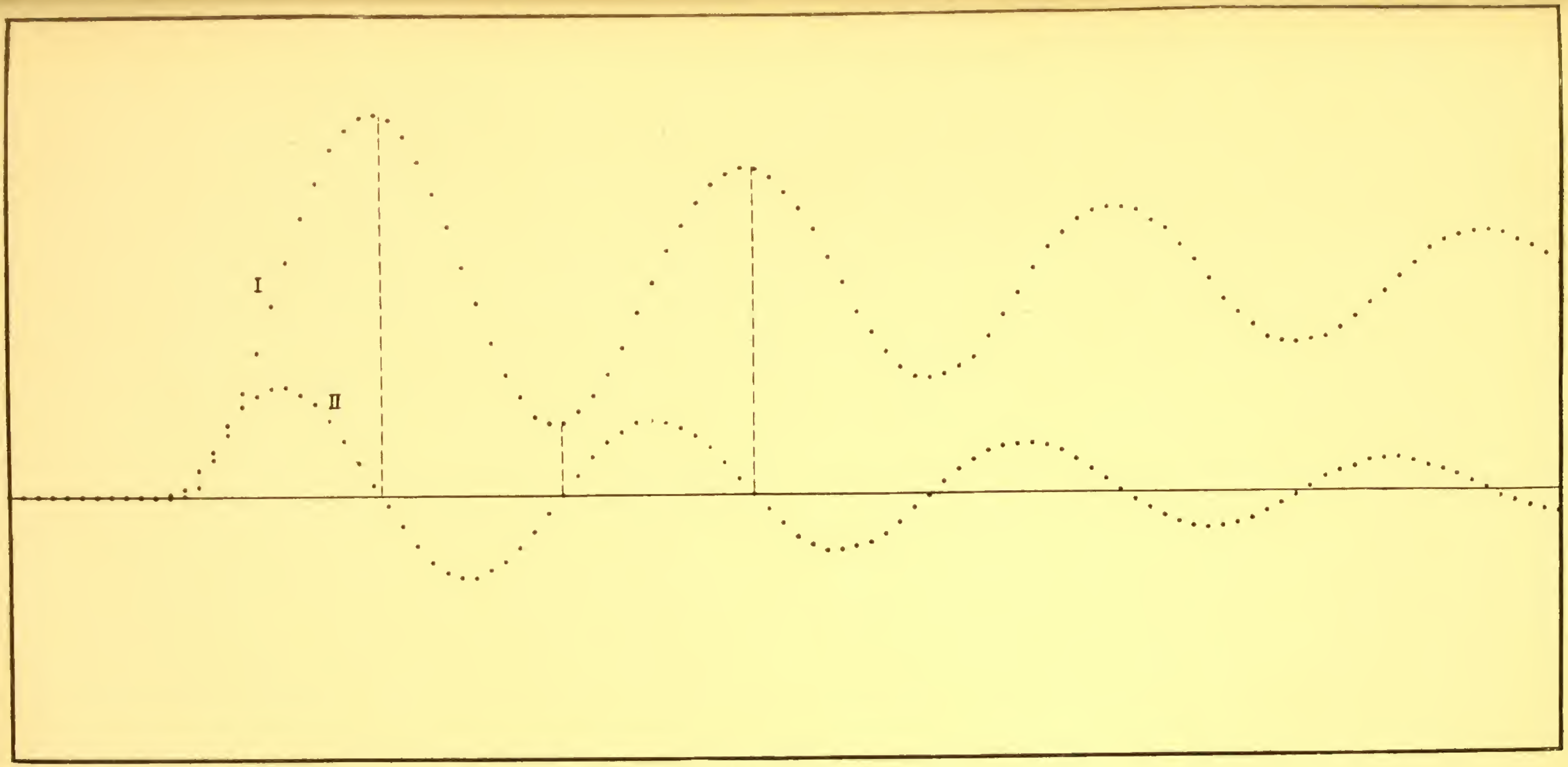


Plate IV

These curves represent the oscillatory charge of a condenser when a direct electromotive force is applied. In this case a storage battery is periodically connected to the condenser by means of a special rotating two-part commutator, and the curve tracer, which revolves at the same rate, gives the curves in the same way that it does for ordinary alternating currents.

Curve I is the difference of potential of the terminals of the condenser, and therefore it may be called the potential curve or the quantity curve.

Curve II is the charging current. The zero points of the current curve correspond to the maxima and minima of the electromotive force curve. Charging voltage was 50 volts. The frequency of the oscillating charge is about 1000 per second.

Plate V

These curves represent the oscillatory discharge of a condenser through an inductive circuit, using the same connections as in the curves of Plate 4.

Curve I is the potential difference at the terminals of the condenser, and Curve II is the oscillatory discharge. The potential begins to drop at the instant the discharge current begins. The first half wave of current not only discharges the condenser but recharges it in the opposite direction. The zero points in the current curve coincide with the maxima in the potential curve. The frequency is the same as in the charge.

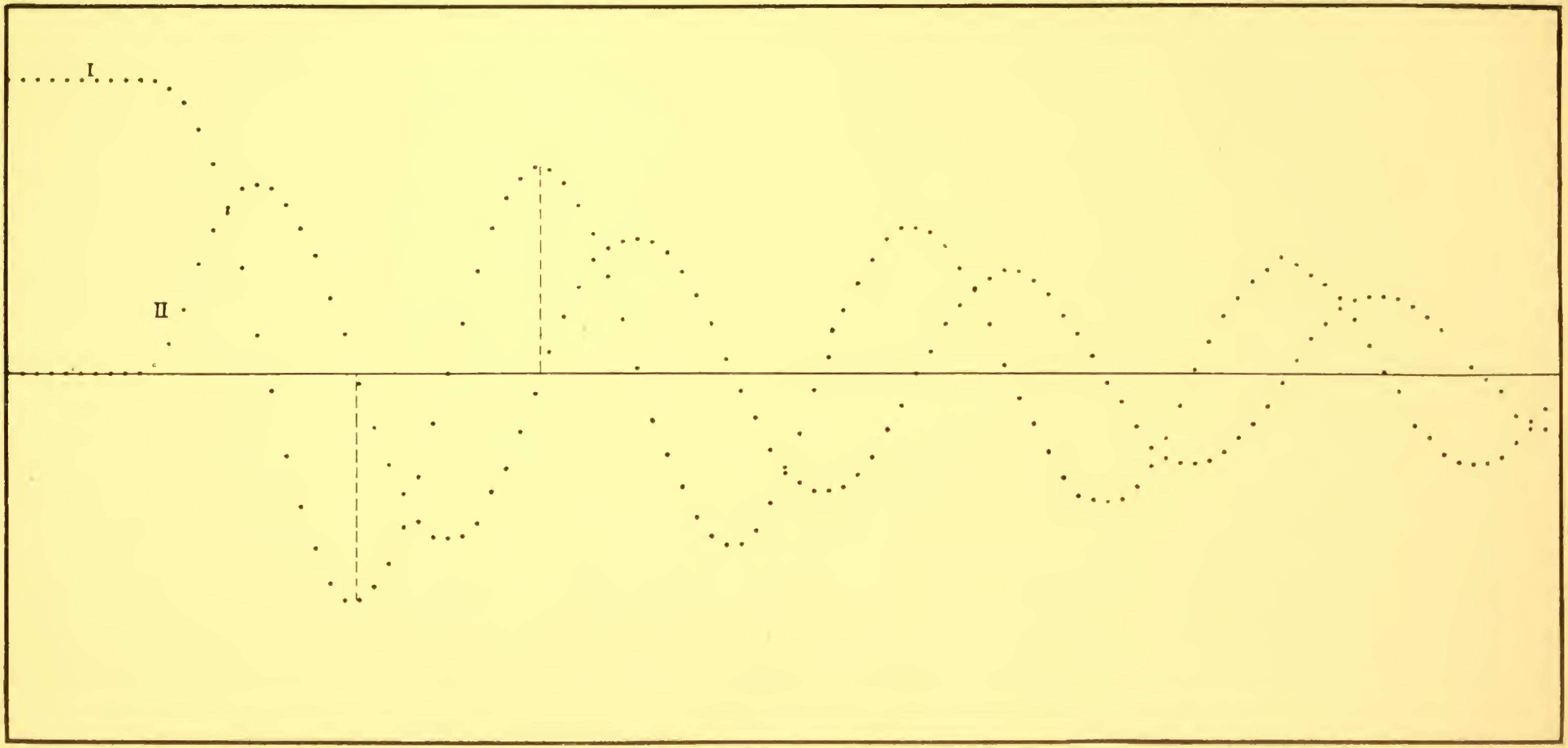


Plate V

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